Network-Growing Scenarios in IEEE 802.15.4 Wireless Sensor Networks

Slobodanka Tomic
Telecommunications Research Center Vienna (ftw.)
Donau-City Strasse 1
Vienna, Austria
tomic@ftw.at

***Abstract*—This poster-paper describes the current work which focuses on analyzing the multi-application requirements and capabilities of wireless sensor networks based on IEEE 802.15.4 and ZigBee standards.**

Keywords-component; multi-application wireless sensor networks

I. INTRODUCTION

Wireless sensor networks (WSN) are complex distributed systems of nodes with sensing, data processing and storage capability, wireless-communication interfaces and, in general, limited power. They are used for the surveillance and control applications in a diverse range of micro and macro environments, such as wild life habitats, urban environments, technical and biological systems and structures [1], [2].

The diversity of potential WSN applications, many of which coming with very stringent requirements and system constraints, has motivated immense research work on communication topics such as power-efficient wireless technology, wireless resource management, medium access (MAC) and routing protocols, collaborative processing and data aggregation, and also work on platform design including hardware miniaturization and software engineering [3].

One of the central research topics in wireless sensor networking is the design of protocols optimized for the constraints of sensor nodes and for requirements of data dissemination in the network. Disseminations requirements are very specific: data from source nodes, potentially highly correlated, may be generated and periodically, on a query, or on a particular event routed, either directly, towards the observer nodes (sinks), or towards aggregation nodes for further processing. Sensing areas may be queried by many observer nodes connected at arbitrary nodes; each query may specify required fidelity, timeliness and reliability. In the past many specific solutions optimized for particular sensing tasks have been proposed and analysed, which brought better understanding of necessary functionality of the general energy-efficient communication stack for wireless sensor networks.

Recently, IEEE approved a standard for medium access layer (MAC) and physical layer (PHY) for low-rate wireless personal area networks (LR-WPAN IEEE 802.15.4) [4]. IEEE 802.14.5 is a multi-optional communication MAC and PHY layer with a medium-size set of primitives that can support a large variety of higher layer protocols. It includes clustering capability and distinguishes between simple sensor nodes with reduced processing capability and power, called reduced functionality devices (RFD), and more advanced sensor nodes or specialized router/gateway nodes with extended storage, processing and communication functionality, called full functionality devices (FFD). IEEE 802.15.4 is an important building block for a standard sensor network communication stack. Complemented with the ZigBee networking and application layer, which is proposed by ZigBee Alliance, it is a synonym for a standard platform for the development of sensor network applications.

Having a standard communication stack is particularly important for *multi application* sensor networks. However, the merit of a fully functional standard stack is still to be verified. Various investigations have demonstrated that *application-specific* energy-aware cross-layer optimization, i.e., the joint design, of MAC, topology control, routing and data fusion protocols have potential to considerably improve the performance of the network. With this in mind, IEEE 802.15.4 MAC and PHY standard is designed to support variety of network organization approaches and therefore a variety of higher-level protocols and different *applications.*

At present, the WSN application scenarios considered in the context of IEEE 802.15.4 usage focus mainly on the case where one sensor network infrastructure is established to support applications. ZigBee further introduces the concept of multiple applications, however it does not distinguish between the underlying resources in terms of different purpose networks. We believe that it is important to consider dynamic multi-application scenarios in which different applications provided over specific infrastructures can *co-exist* and collaborate and share infrastructure. Multiple applications may share communication resources and the in-network processing capability.

We are interested in examining requirements and potential benefits of a protocol layer with mechanisms for application-aware *resource sharing* between applications of different performance requirements. In our study we base this layer on the IEEE 802.15.4 MAC and PHY standard. We define WSN growing scenarios and examine the requirements of the infrastructure sharing and the applicability of the existing standard options.

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II. Scenarios for Network Growing

We define three so-called *"network growing"* scenarios, in which the network is enhanced by incrementally adding new nodes, and by incremental introduction of new sensor network applications. Starting from a simple scenario and moving towards more challenging ones we want to examine how IEEE 802.15.4 networks (WPAN) can self organize to support sensor application coexistence and inter-working. The scenarios under consideration are described and illustrated below.

1) Infrastructure Extension Scenario (S1): In this scenario new nodes are added to the existing infrastructure, providing new resources and extending the network coverage. The nodes may be data sources or data sinks or simple relays. We assume that one single application AP1 is deployed in network nodes. When a node is added it attempts to join the existing data dissemination infrastructure of the WPAN. The challenge here is the task-aware and resource-aware network re-organization.

Example of a cluster tree is shown in Fig 1. A node (m) attempts to join a beacon-enabled cluster tree. A node (m) may join at (4) or (10). If a tree corresponds to the data dissemination requirements of a beacon-controlled and scheduled tree, both associations are equal. If however (m) is to be send data to (21) the choice of the binding node is important. The benefit of potential re-configuration of the tree, that is, (10) associates with (20), could also be investigated.

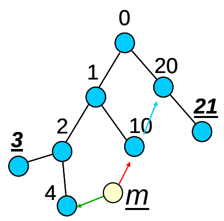

Figure 1. Joining a Cluster Tree

Example of extending a mesh network is shown in Fig 2.

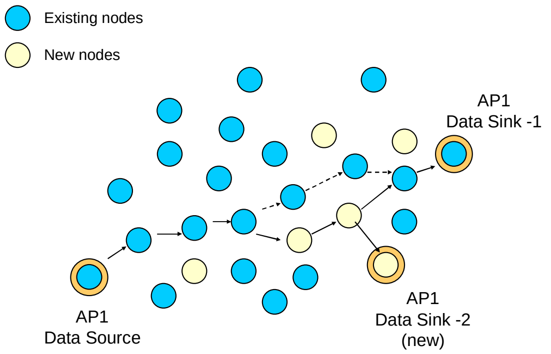

Figure 2. Extending a Mesh Network

In this example six new nodes (one data sink and five routers) are added to the mesh network. Resource and application aware routing should be able to automatically select the new route towards the new data sink.

2) ***Infrastructure Collaborative Sharing (S2):*** *In this scenario,added sensing nodes that make an infrastructure for a new sensing application AP2 are deployed in the area with the existing WPAN supporting the application AP1. AP1 and AP2 may operate in separation but may also share infrastructure to enhance reliability. The challenge of this scenario is to establish application awareness in the sub-set of nodes.*

Example is shown in Fig 3.

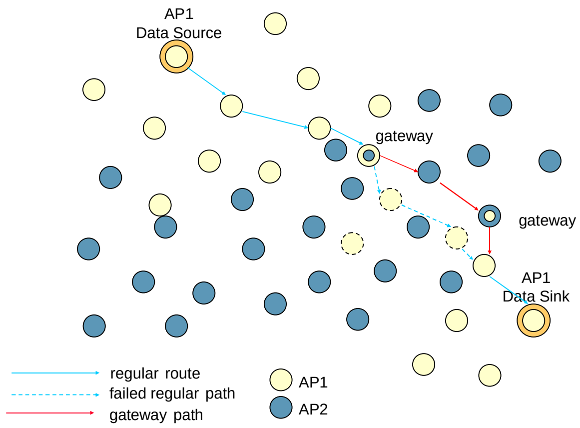

Figure 3. Two Application Collaboration

An application AP1 can use the infrastructure introduced with AP2 if the gateway functionality can be established. The nodes of both WPAN2 (blue) and WPAN1 (yellow) should be application aware.

3) ***Application-aware Self-Organization (S3)****: Here, new sensing end-nodes with application AP2 are additionaly deployed in the existing WPAN with AP1. This WPAN may be extended with several new nodes. Both applications use the existing WPAN but there may be a need for the WPAN to re-organize (e.g., to split into two WPANs) to best support the application requirements. The challenge of this scenario is the design concepts for dynamic self-configuration and resource-sharing.*

S1 is a simple single-application scenario. The focus is on the mechanisms for the network organization (network creation, joining a network) and reaction to the changes of network topology. Added nodes may have different capabilities, regarding power, computation, and storage. Therefore, the protocols should support *resource-aware* re-configurations based on IEEE 802.15.4 MAC layer clustering primitives. Scenarios S2 and S3 impose greater challenges, as the notion of the application and infrastructure coexistence, inter-working and resource sharing need to be established. The trivial approach to coexistence of several WPANs is a physical separation. This is supported by IEEE 802.15.4 where different channels can be allocated to different networks for non-interfering operation. Scheduling with active and sleeping periods can further support both sharing and separation of resources, depending on the specific requirements.

Detailed consideration of these three scenarios shows that the concepts of sensor network applications and infrastructure resources, although existent partially in IEEE 802.15.4 and partially in ZigBee NWK and APP layer are not fully coherent. Basic network creation mechanisms are aware of channel allocation and link quality but are not aware of other resources and application specific requirements. In a multi-application network with many possible alternative data sinks and network aggregation points, network nodes take part in sensing, sending data, aggregating and forwarding data and may act as data sinks. Nodes can support different applications and tasks according to capabilities and current state. Therefore they need to make decisions such as which communication, aggregation and processing tasks they shall perform in any particular moment. In general this is a problem of sharing resources and scheduling, which requires prioritisation of tasks.

III. Networks and Applications in IEEE 802.14.5 LR-WPAN and ZigBee

IEEE 802.14.5 LR-WPAN is a multi-optional standard that can support various higher layers. LR-WPAN architecture supports clustering. Three different types of device roles are defined: a simple device (non-router), coordinator and a PAN coordinator. WPAN can be organized as a beaconed or a non-beaconed network. Both the contention-based and the bandwidth guaranteed medium access are supported. At the physical layer the network nodes can use a number of channels. A node can perform an active or a passive scan to determine availability of channels. Each packet that is received is tagged with a quality indication by a PHY layer. However, the WPAN MAC and PHY have no notion of the node resources and energy. At the network layer ZigBee standard supports node starting, network discovery, network formation and routing on a cluster tree and in a mesh network. A cluster tree provides an address assignment mechanism for simple tree routing. For mesh network a reactive routing protocol is proposed which uses on-demand route discovery. However, network formation and discovery does not account for resource availability or application support in the nodes. We believe, that in the context of the network growing scenarios this is not sufficient.

In a ZigBee stack resource availability and application information is modelled in form of different descriptors in the application layer. The node and power descriptor describe the capabilities such as whether the device is battery powered or mains powered and the information on the residual energy graduated as 30% 60% and 100%. Further information includes node type (coordinator, router, end-node), maximum buffer size, the receiver-on policy, etc. At the application layer the ZigBee standard introduces a concept of application profile IDs for identification of applications and the concept of endpoints, as an equivalent of ports, at which applications can “listen”. Each node can support 240 endpoints and applications listening on them. Further each application is specified with its input and output attributes which may correspond to data sinks and data sources and are referred to as input clusters and output clusters.

An important concept in the ZigBee is the application-specific binding between the clusters at the endpoints of the nodes. This binding may be established and configured in the binding tables of coordinators. Data is forwarded (indirectly routed) towards the nodes with the binding tables which may than determine further next hop.

ZigBee further defines primitives for the discovery of resource and application descriptors’ data. However, this discovery can only follow the initial network formation. In the context of the network growing scenarios it seems that the resource and application discovery must be more directly incorporated in the initial topology control. We are therefore proposing and investigating the Application-Aware WPAN Creation mechanisms.

IV. Application-Aware WPAN Creation

Application-aware WPAN formation is based on the resource and application advertisement and discovery. These use IEEE 802.15.4 MAC primitives for passive and active scanning and network association. However they extend the neighbour information with the application-specific and resource specific information. This is further the basic for the extensions in the NWK layer

Advertisement/Discovery includes:

- Scan for active networks and send advertisement messages (or discovery messages) of resources and application cluster information
- Wait for “requests for bindings”
- Select and bind
- Send “accept binding”

Discovery and advertisement differ in the amount of the information initially sent. Discovery messages carry less information and the requests for binding provide more possibilities for the binding choice. Advertisement messages carry more extensive information and therefore there may be less received potential bindings.

V. Performance Evaluation

To analyze the performance we use the existing ns-2 [5] implementation of the IEEE 802.15.4 protocol. We are currently implementing the application-aware WPAN Creation modules which use the standard primitives to the highest extent. We also plan to investigate the applicability of the ZigBee networking layer in the proposed scenarios.

Acknowledgment

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